A STUDY OF THE SWITCHING ACTION IN A MULTIVIBRATOR CIRCUIT. PART I

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(Plates XIIA, B and C)

ABSTRACT. An experimental arrangement for taking oscillograms of the rapid changes in the electrode voltages when current transfers from one tube to another in a plate-coupled multivibrator is described. Oscillograms with different values of the circuit parameters are shown The results of this investigation are summarized

INTRODUCTION

The multivibrator circuit has come into extensive use in the electronics of television, radar and experimental nuclear physics. Its wide application no doubt promoted extensive studies on its mode of operation. As a result much of it is now well-known. The author had the opportunity of exploiting this circuit in a variety of ways, chiefly in experimental nuclear physics (Banerjee, 1945). He has also made some new observations on this circuit. It is felt that the literature published up till now* (Donald, 1947, etc) fails to give proper importance to and clarify adequately the phenomenon occuring at the time when switching takes place, *i e*, when current from one valve transfers to the other. It is therefore intended to deal with this particular part of multivibrator action in a series of publications.

SWITCHING ACTION IN A MULTIVIBRATOR

For clarity and convenience, the mode of operation of the multivibrator circuit will be discussed briefly. The multivibrator may be described as a two-stage resistance-capacity coupled amplifier in which the output is fed back to the input. The plate-coupled circuit is shown in (Fig. 1). When such a circuit is connected to the high tension supply, current

* The literature (Kiebert and Inglis, 1945) and text books (M. I T. Staff, 1946) (Fink, 1947) published until very recently do not deal with the switching phenomenon in any detail—nor do they give the facts in a summarized form as has been done in this paper. Williams *et al* (1950) present the results of a theoretical analysis on the switching action of a multivibrator circuit. They discuss the effects of circuit parameters on speed of switching in connection with the discussion on triggering delay in triggered switching, the determination of which is the chief aim of their paper. In the chapter on "Generation of fast waveforms" ("Waveforms", by David Sayre McGraw Hill & Co., 1949) the methods of obtaining "fast switching" has been discussed Sayre also attempts for a theoretical analysis of the switching action. The theoretical analysis by the author which will come out in the second part of this paper is more complete and is somewhat different.

alternately switches from the tube T_1 to T_2 and switches back from T_2 to T_1, at regular intervals. We shall study what happens at the time of switching. The plate-coupled multivibrator will be discussed first.

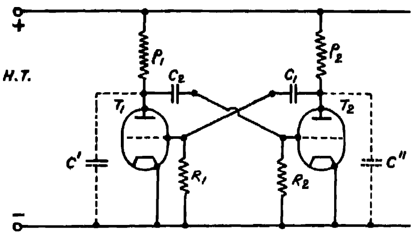


Fig. 1

Starting with the condition in which T_1 current is flowing and T_2 current shut off, let us examine the phenomenon when current transfers from T_1 to T_2. In T_2 grid voltage advances slowly towards zero from the high negative value it attained previously when current in T_2 was shut off. This is due to the negative charge in the condenser C_2 leaking off through R_2. As the grid voltage crosses the cut off limit, current flows again through T_2. The feedback chain is completed and the regenerative switching process starts. Current rapidly increases in T_2 and diminishes in T_1. Within a short time—one or two microseconds, current in T_2 rises to the maximum limit and that in T_1 cut off completely. Thereafter the anode voltage of T_2 and the grid voltage of T_1 go on falling ; the anode voltage of T_1 goes on rising, while the grid voltage of T_2 diminishes slightly. Within another short period of a few microseconds (or a few tens of microseconds), the anode voltage of T_2 and the grid voltage of T_1 drop to their lowest values and the anode voltage of T_1 approaches the maximum value, the H.T. line voltage. The whole phenomenon may therefore be considered to consist of two distinctly separate parts, *viz.*, the switching of currents in the tubes in the first one or two microseconds and the completion of the consequent voltage changes in the following few microseconds or few tens of microseconds. This latter part appears to be fairly well known now-a days. Before World War II, it was belived that the whole phenomenon takes place immediately.

The changes of current and voltage that take place at the time of switching on absorb finite time, few microseconds, because some stray capacities, indicated by C' and C'' (Fig. 1) are to be charged and discharged through finite resistances. The first part of the switching process in which the current is flowing in both the tubes T_1 and T_2, is a regenerative process and is an exponential one with positive index. We shall discuss this part in a later publication. An experimental set up for oscillographic study on a free-running multivibrator will be described in this publication. The second part of the switching phenomenon has been ~~and~~ studied in the first phase of these experimental investigations. The results of these investigations will be summarized and explained. As mentioned before, these appear to be well known. A new experimental arrangement is described in the present paper.

EXPERIMENTAL ARRANGEMENT

The experimental set-up consists of the following parts :

(1) The multivibrator ~~to be~~ on test~~ed~~.

(2) An isolating cathode follower tube for applying the test multivibrator electrode voltage to one plate (Y_1) of the double-beam cathode ray tube.

(3) A synchronized high-speed sweep which may be adjusted to start just before the switching takes place.

(4) A time marker arrangement feeding a shocked sine wave to the other plate (Y_2) of the double beam cathode ray tube.

(5) An intensifying arrangement to switch on the cathode ray beam at the forward stroke of the high speed sweep.

The circuit diagram is given in Fig. 2.

The test multivibrator consists of two 6SJ7 tubes connected as a free running plate-coupled multivibrator. The 6SJ7 tubes may be connected as a triode or a pentode. The isolating cathodes follower consists of two sections of the double triode 6SN7 in parallel. The grids may be connected to any electrode of the test multivibrator. The cathode feeds the oscilloscope plate Y_1 and deflects the corresponding beam of the double beam tube. The oscilloscope plate receives a voltage signal at low impedance which is the same as the signal on the grids of the cathode follower. The multivibrator electrode under investigation is loaded only with the relatively small input capacity of the cathode follower compared to the cathode ray tube. The remote end of the cathode resistance goes to the +45 volts of the dry battery when plate voltages are measured and to −60/120 volts when grid voltages are to be measured. The plates of the cathode follower may be connected to the +300 volt or +500 volt supply.

The synchronized high speed sweep produces a saw tooth sweep voltage which may be adjusted to start just before the switching takes place. It consists of the 6SN7 synchronizing amplifier, the 50 pf, 5 k differentiating circuit, the 6SJ7 biased amplifier, the 6SN7 sweep multivibrator locked to the test multivibrator frequency, the 6SH7 sweep generator and the 6H6 diode clamp tube. Its mode of operation is given below.

The grids of the tube T_1 of the test multivibrator and that of the synchronizing amplifier are connected together When the test multivibrator is

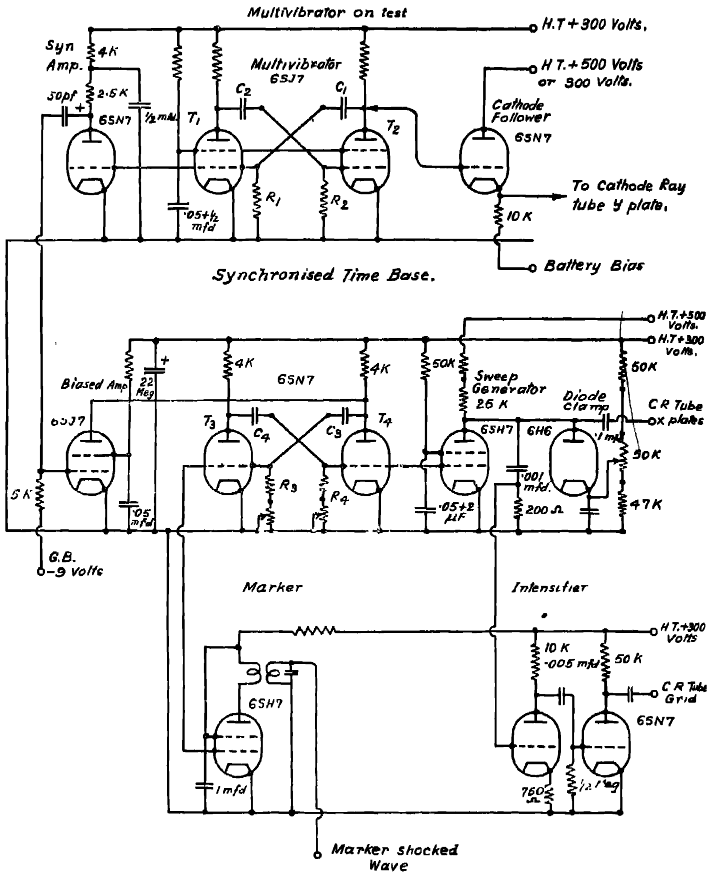


FIG. 2

switched on, T_1 is cut off and synchronizing amplifier tube is also cut off. The positive rectangular pulse at its anode is differentiated by the 50 pf., 5 k circuit to form a positive spike at the grid of the 6SJ7 biased amplifier. The positive spike passes through this 6SJ7 tube biased to cut off and triggers the sweep multivibrator—bringing about current transfer from T_3 to T_4. This marks the synchronized zero time of the whole period and the system.

The switching of the sweep multivibrator drives the voltage of the grid of T_4 to a little positive above zero and together with it the grid of the sweep generator 6SH7, as they are connected together. The .001 Mfd. sweep capacitor therefore discharges through the 6SH7 sweep tube.

The sweep multivibrator switches back after some time, as T_3 grid voltage comes near zero from the high negative value it attained at zero time—the time of the triggered switching. This time τ_3 depends upon C_3R_3. When the sweep multivibrator switches back and current is transfered from T_4 to T_3, T_1 grid becomes highly negative and its anode current is cut off. The 6SH7 sweep tube is simultaneously cut off. The .001 Mfd. sweep condenser therefore charges through the 50 kilohm resistance at the plate of the 6SH7 tube. This is applied to the oscilloscope Plates X through the 0.1 Mfd capacity and produces the forward sweep. As the sweep condenser voltage exceeds the voltage set by the cathode potentiometer of the diode clamp tube, it conducts and prevents further rise of condenser voltage during the sweep. The exponential sweep is thus brought to a halt and is confined to the nearly linear region.

As the test multivibrator switches back, current is transferred from T_2 to T_1, after a time τ_1 which is determined by C_1R_1.

If τ_3 is made just smaller than τ_1 by adjusting of R_3 and C_3, the forward stroke of the sweep starts just before this switching (from T_2 to T_1) in the test multivibrator. The voltages at this switching time are therefore delineated on the greatly expanded sweep of the oscilloscope and their variations in times of the order of microseconds become observable.

The test multivibrator switches again, from T_1 to T_2, after another time τ_2, determined by C_2R_2. This marks the completion of one period and the sweep multivibrator is again triggered. The sweep multivibrator must not switch, of itself, earlier. If the sweep multivibrator were allowed to run free, it would have taken a time τ_4 dependent upon C_4R_4, for the return switching. Thus the total period of the test multivibrator is $(\tau_1+\tau_2)$ and the total period of the sweep multivibrator when allowed to run free is $(\tau_3+\tau_4)$. For proper synchronization $(\tau_3+\tau_4)$ must be greater than $(\tau_1+\tau_2)$. If this condition is not satisfied, the sweep multivibrator will complete its period and switch on by itself before the test multivibrator has switched on and thus cannot be synchronized with the test multivibrator. Thus the following two conditions are to be satisfied for proper adjustment,

τ_3 just smaller than τ_1, and

$(\tau_3+\tau_4)$ greater than $(\tau_1+\tau_2)$.

These are accomplished by adjusting the continuously variable resistances R_3 and R_4 and by changing C_3 and C_4 until suitable values are obtained. These adjustments are most easily made with the double-beam oscilloscope. After removing the synchronizing link between them, the test multivibrator signal and the sweep voltage are both applied to the two oscilloscope plates. These are alternately locked with the internal time base of the oscilloscope and their frequencies estimated. Keeping the variable parts of R_3 and R_4 at about half values, the frequency of the sweep multivibrator is made smaller than the test multivibrator by adjustment of R_3, R_4, C_3 and C_4. Then the synchronizing link is restored and the continuously variables in R_3 and R_4 adjusted until the forward stroke of the sweep is seen to come at the switching time. The internal time base of the oscilloscope is then disconnected and the circuit time-base is applied. Adjustment of R_3 brings the switching phenomenon at the desired position in the expanded sweep. (Fig. *a* and *b* in Plate XIIA).

The time marker is provided by shocked oscillations in an L C circuit. At the forward sweep of the time-base, *i.e.*, when current in the sweep multivibrator transfers from T_4 to T_3, T_3 grid is powerfully driven positive. As the grid of the 6SH7 (shocked oscillation tube) is connected to T_3, it is also driven positive The sudden burst of current in the primary of the oscillator coil excites a powerful damped oscillation at the natural frequency of the LC circuit. This is applied to the second beam of the oscilloscope tube and used as a time marker.

The intensifier consists of a two stage resistance coupled amplifier which derives its input from the 200-ohm resistance in series with the sweep condenser. The charging current of the sweep condenser produces a small positive voltage across this resistance with respect to ground. The amplified voltage of a magnitude of about 100 volts positive, is applied through a high voltage coupling condenser, to the cathode ray tube grid. It therefore switches on the normally shut off beams at the forward stroke of the time base. This unblanking voltage remains positive only so long as the sweep condenser charges, *i.e.*, only when the cathode ray spot moves in the forward direction. As soon as the spot movement stops, due to conduction in the clamping diode, the positive voltage goes off and the cathode ray beams are blanked out. There is no opportunity for steady spots remaining illuminated to produce halo and reduce visibility in this circuit.

RESULTS OF EXPERIMENTS

Oscillograms of rise of plate-voltage in tube T_2, fall of grid voltage in T_2 and fall of plate voltage in T_1, with plate load resistances of 600,000 ohms, 100,000 ohms and 20,000 ohms, both when the 6SJ7 tubes were connected as triodes as well as pentodes will be found in Plates XIIA, B and C. ~~By~~ When connecting as a pentode, the common screen dropping resistor was made equal to twice the corresponding plate resistance. The condensers C_1 and C_2 were both 15 pf. tubular ceramic condensers and the grid leaks R_1 and R_2 were one megohm carbon resistors of small size. The 15 pf. 1 Meg. combination gave a relatively small repetition time and was necessary to minimize "jitter" of the oscilloscope patterns. A few oscillograms with 50 pf.

ceramic condensers for C_1 and C_2 will also be found in oscillograms *o*, *p*, *q*. Besides, oscillogram (*a*) in Plate XIIA shows the grid voltage of T_2 together with that of the synchronized sweep on the internal time base of the Cossor model 339A oscilloscope and the same grid voltage with the expanded synchronized sweep Further oscillograms (*n*) and (*s*) prove the simultaneous beginning of the rise of grid voltage in tube T_1 and fall of grid voltage in tube T_2, and the rise of plate voltage in tube T_2 compared with the fall of plate voltage in tube T_1.

The oscillograms were taken on a Cossor model 339A oscillograph using a 09D double-beam tube. This tube retains admirably good focus with large assymetric deflection voltages and with the large change of grid voltage needed for full intensification of the forward sweep.

The time marker circuit provides a damped sine wave of 1.1 Mc/s, generated by shock excitation of a high '*Q*' tuned circuit. The repetition frequency of the test multivibrator altered with changes of plate load resistance They were measured by comparing with the sine waves from a beat oscillator.

The results may be summarized broadly as follows:

(1) The rise of plate voltage with time is exponential and has a time constant approximately given by $C_1\rho$.* It may be represented by the equation

(H. T. Voltage − Plate voltage) =

(H T. Voltage − Plate voltage at start of switching) $\exp - t/C\rho$.

This voltage changes very slowly compared to all other electrode voltages. This is directly affected by changes in the coupling capacity C_1 and by changes in the load resistance ρ.

(2) The fall of plate voltage with time is roughly exponential † and has a time constant dependent mainly upon the stray capacitances C' (sum of tube output and input capacitances plus the wiring capacity) and the plate resistance of the tube. This change of voltage is the most rapid of all the voltage changes. It is affected by changes of the plate load resistor by a small amount—an increase in the plate load resistor diminishing the rapidity of the change. Changes in the coupling capacity produce a still smaller change in the rapidity of fall—an increase of capacity increases the rapidity.

(3) The fall of grid voltage is a complicated function of time, a combination of two exponentials, roughly. It is dependent mainly on the same factors as those which control the plate voltage fall, being derived from it.

* For accurate estimation, C_1 must include the stray capacities across the plate of T_2.

† The divergence from an exponential curve is very great, yet it is so called because the simple theory indicates an exponential.

It is affected greatly by C_2R_2; an increase of C_2R_2 produces an increased rapidity. It is slower than the fall of plate voltage but may be faster or slower compared to the rise of plate voltage.

(4) When the magnitude of the plate load resistors are equal to or slightly greater than the tube plate resistance, and the coupling capacities are comparable to or as small as the stray capacities, the rise and fall of plate voltage are almost equally rapid, (compare oscillograms of $20k$ load resistance), while the fall of grid voltage is slower than either.

(5) The rise of plate voltage is affected little by a change from triode to pentode connection The fall of plate voltage and grid voltage are affected appreciably, the chief difference being a slight change in the character of these waveforms. However, the slopes are not appreciably greater with multivibrators using pentodes, so that when rapid switching is desired, multivibrators using triodes may be as good as multivibrators using pentodes.

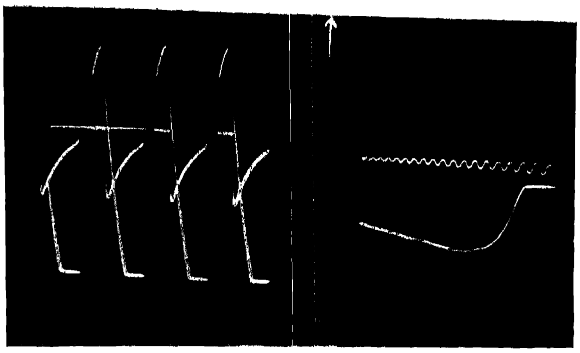
CONCLUSION

The switching action—the phenomenon that takes place in a multivibrator when current transfers from one tube to another, has been studied in this paper. The switching phenomenon is divided into two parts. In the first part, currents in the two tubes change—increasing to the maximum limit in one tube and decreasing to zero in the other. The voltage changes during this current transfer are usually small—of the order of five to fifteen volts. This completes itself within the first one or two microseconds. After this current transfer, the electrode voltages go on changing and reach their final values within another few or few tens of microseconds. This change is considerable, being a good fraction of the H. T. supply voltage. Oscillograms of this switching action has been taken with the help of a circuit that starts a high-speed sweep just before the switching. The second part of the switching phenomenon is shown clearly in these oscillograms. The first part occupies relatively small portions of these oscillograms and hence no comments are made as to its nature. The results of these investigations with regard to the second part are summarized above.

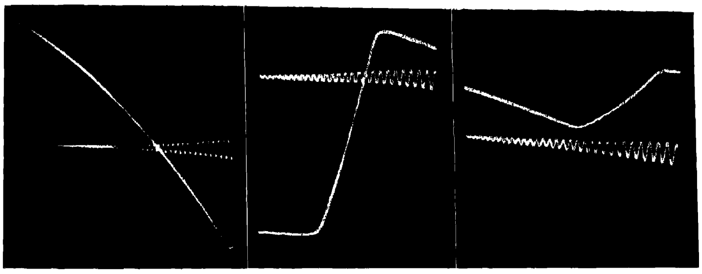
The switching action in a multivibrator is important because waveforms generated when switching very often form the basis of the timing signals utilised in radar, television and experimental nuclear physics. A critical knowledge of this switching phenomenon is helpful in obtaining increased accuracy of timing, ~~which is~~ so very important in the proper functioning of these systems.

OSCILLOGRAMS

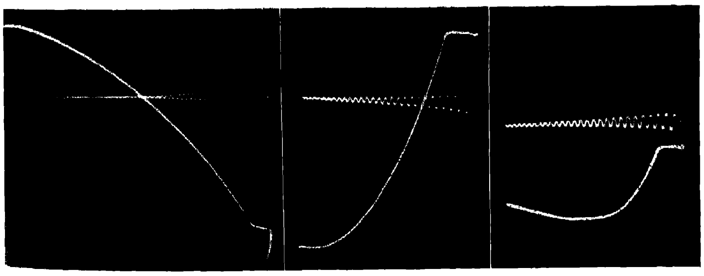
Oscillograms were taken on a four-inch Cossor double-beam oscilloscope (Model 339 A).



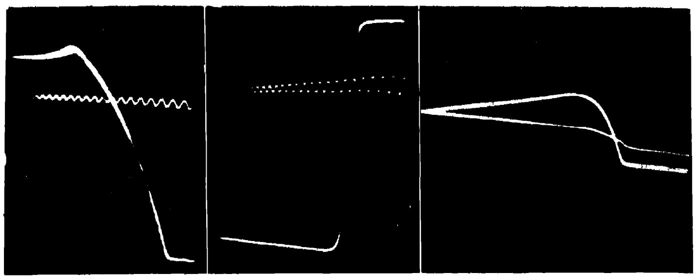
a *b*



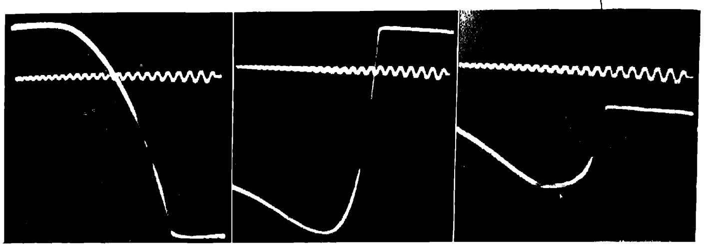
c *d* *e*



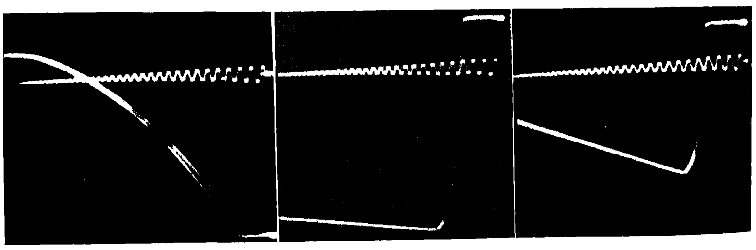
f *g* *h*



l *m* *n*



l *i* *j* *k*



o *p* *q*

The cathode ray spot moves from right to left at the forward stroke of the high-speed sweep. The damped oscillation of the time marker is from a high Q LC circuit that resonates at 1 1.Mc/s.

The switching phenomenon was studied on a symmetrical circuit in which $\rho_1=\rho_2$, $C_1=C_2$, $R_1=R_2$; the stray capacitances C' and C'' are also nearly equal; (see Fig. 1). As a result it is immaterial as to which of the tubes is utilised to get the oscillograms. Thus the plate voltage rise in T_1 will be the same as that in T_2; the plate voltage fall in T_2 will be the same as that of T_1; the grid voltage fall in T_1 will be the same as that in T_2; the grid voltage rise in T_2 will be the same as that of T_1. While the latter of the tubes referred to above were usually exploited in the experiments, it was verified that this conclusion generally holds true ~~for all~~.

As the rise in grid voltage is usually too small to be of much experimental value, most of these oscillograms have been omitted.

Oscillogram (*a*) in Plate XIIA top left, shows the synchronized high-speed sweep (long up-and-down strokes) and the grid voltage of T_2 (the smaller pattern in the middle of the oscillogram) It will be seen that the forward stroke of the sweep—the long line from top to bottom—is synchronized with the fall of grid voltage of T_2.

Oscillogram (*b*) in Plate XIIA top right, shows the fall of grid voltage in T_2 expanded on the highs-peed sweep. The cathode ray spot moves from right to left at the forward stroke of this time base.

Oscillograms (*c*), (*d*), (*e*) show respectively the plate voltage rise, plate voltage fall, and grid voltage fall, where T_1 and T_2 are two 6SJ7 tubes connected as triodes with plate load resistances $\rho_1=\rho_2=600,000$ ohms, coupling capacities $C_1=C_2=15$ pf and grid leak resistances $R_1=R_2=1$ Meg. The repetition frequency was 6800 c.p.s.

Oscillograms (*f*), (*g*) and (*h*) similarly show the plate voltage rise, plate voltage fall and grid voltage fall respectively with the same circuit constants as above but with the 6SJ7 tubes connected as pentodes. Repetition frequency=6500 c.p.s.

Oscillograms (*i*), (*j*) and (*k*) in Plate XIIB show respectively the plate voltager ise, plate voltage fall and grid voltage fall where T_1 and T_2 are pentode connected and $\rho_1=\rho_2=100,000$ ohms Other circuit constants are same as before Repetition frequency=8900 c.p s.

Oscillograms (*l*), (*m*) and (*n*) in Plate XIIB similarly show the plate voltage rise, plate voltage fall and grid voltage rise and fall, with T_1 and T_2—6SJ7tubes of as triode connected. Other circuit constants are same as those for oscillograms (*i*), (*j*), (*k*). Repetition frequency=9500 c.p s.

Oscillograms (*o*), (*p*), (q) in Plate XIIB show the plate voltage rise, plate voltage fall and grid voltage fall respectively, with connected tubes as 6SJ7 triode and with coupling capacities of 50 pf for C_1 and C_2. Other circuit constants and same as those for oscillograms (*i*), (*j*), (*k*). Repetition frequency =4650 c.p.s.

Oscillograms (*r*), (*s*), (*t*) in Plate XIIC show respectively the plate voltage rise, plate voltage rise and fall superimposed, and grid voltage fall with triode connected 6SJ7 tubes and with $\rho_1 = \rho_2 = 20{,}000$ ohms. $R_1 = R_2 = 1$ Meg. and $C_1 = C_2 = 15$ pf, same as in other oscillograms. Repetition frequency = 14,400 c.p.s.

Oscillograms (*u*), (*v*), (*w*) in Plate XIIC are respectively the plate voltage rise, plate voltage fall and grid voltage fall with pentode connection of 6SJ7 tubes and other circuit constants remaining same as in (*r*), (*s*), (*t*). Repetition frequency = 8500 c.p s.

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REFERENCES

Banerjee, B. M , 1945, *Ind. Jour Phys.*, **19**, 75.

Banerjee, B. M , Saha A. K. and Ghosh, A., 1946. *Proc. Nat. Inst. Sciences Ind.*, **12**, 173

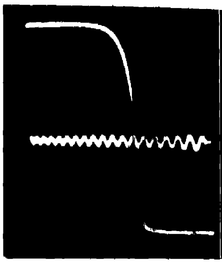
Sayre, 1949, Waveforms, Chapter V, pp. 159-204. McGraw Hill.

Donard G. Fink, 1947, Radar Engineering.

Kiebert and Inglis, 1945, *Proc I. R. E.*, **33**, 534.

M I T., Staff, 1946, Principles of Radar, Second Edition

Williams, Aldrich and Woodford (1950), *Proc I. R. E.*, **38**, 65.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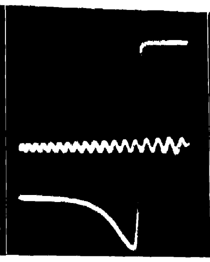
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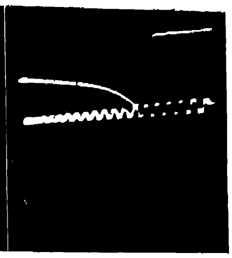
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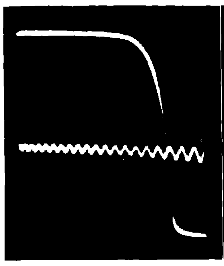
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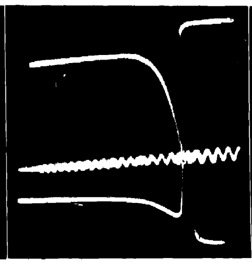
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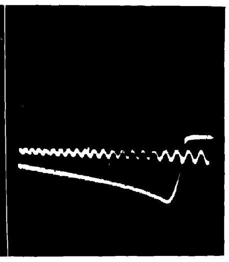
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